PREDICTING *VIOLA GUADALUPENSIS* (VIOLACEAE) HABITAT IN THE GUADALUPE MOUNTAINS USING GIS: EVIDENCE OF A NEW ISOLATED POPULATION

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ABSTRACT

Viola guadalupensis is a rare endemic of the Guadalupe Mountains in West Texas. Isolated to a remote limestone, rock face, this species was known only to exist at a single location along the East Rim of Frijole Ridge within Guadalupe Mountains National Park (GMNP). Despite traditional surveys in seemingly suitable habitat, researchers had been unable to locate new populations. Its small population size, genetic isolation, and lack of significant habitat information make this species vulnerable to extinction. Consequently, the Resource Management Office of GMNP has implemented a strategy to introduce laboratory-germinated plants to new sites in an attempt to preserve this species' viability. Geographical Information Systems (GIS) have previously been successful at predicting suitable habitats of rare species; therefore, we developed a GIS-based habitat model – generated from the elevation, aspect, and slope specific to the type locality – that displayed a map predicting suitable *V. guadalupensis* habitat throughout the park. We ground-truthed nine of the 14 locations produced by the habitat model. One location accurately predicted the type locality, while a second location revealed a new population of *V. guadalupensis* within a steep, slot-canyon drainage along Frijole Ridge. Three locations were determined to be suitable for *V. guadalupensis* introduction and four were considered unsuitable. Considering our model accurately predicted the type locality and discovered a new population, despite traditional survey efforts, the usefulness of GIS-based habitat models for surveying rare species is reaffirmed, providing baseline information for further investigation.

Key Words: Geographical Information System, GIS, Violaceae, *Viola guadalupensis*, Guadalupe Mountains, habitat model, validation

RESUMEN

Viola guadalupensis es un endemismo raro de las montañas Guadalupe en el oeste de Texas. Aislada en una pared caliza apartada, esta especie se conocía en una sola localidad a lo largo del borde este del Frijole Ridge en el Guadalupe Mountains National Park (GMNP). A pesar de las tradicionales búsquedas en hábitats aparentemente apropiados, los investigadores no habían localizado nuevas poblaciones. Su pequeño tamaño poblacional, aislamiento genético, y la falta de información sobre el hábitat hizo a esta especie propensa a la extinción. Consecuentemente, la Resource Management Office del GMNP ha implementado una estrategia para introducir plantas germinadas en laboratorio en nuevos lugares en un intento de preservar la viabilidad de esta especie. Los Sistemas de Información Geográfica (GIS) han tenido éxito al predecir hábitats adecuados para especies raras; por ello, desarrollamos un modelo de hábitat basado en GIS—generado a partir de la altitud, aspecto, y pendiente específica de la localidad tipo– que mostró un mapa que predecía los hábitats adecuados para *V. guadalupensis* en todo el parque. Comprobamos sobre el terreno nueve de las 14 localizaciones producidas por el modelo de hábitat. Una localización predijo con precisión la localidad tipo, mientras que una segunda localización reveló una nueva población de *V. guadalupensis* en una grieta de un cañón abrupto de drenaje en la Frijole Ridge. Se determinaron tres localizaciones como adecuadas para la introducción de *V. guadalupensis* y cuatro fueron consideras inadecuadas. Considerando que nuestro modelo predijo con precisión la localidad tipo y descubrió una nueva población, a pesar de los esfuerzos tradicionales de reconocimiento, se reafirma la utilidad de los modelos de hábitat basados en GIS para el estudio de especies raras, aportando un punto de referencia para investigaciones posteriores.

Habitat models developed from Geographical Information Systems (GIS) are useful tools for predicting the distribution of rare species, decreasing the ineffectiveness of random surveys, providing potential sites for relocation, and aiding the overall development of conservation management plans (Vogiatzakis 2003; Imm et al. 2001; Wu & Smeins 2000). Van Manen et al. (2005) developed a predictive GIS-based habitat model

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derived from the variables of known plant locations for a variety of species in Shenandoah National Park, VA. The efficacy of their predictive model at locating species of interest was 4.5 to 12.3 times more efficient than random surveys. Husveth (2003) used a baseline GIS model generated from observed plant locations, surficial geology, and major soil associations to predict likely sites for rare plant species in a 15,378 ha plot of Anoka County, MN. Field validation surveys (i.e. ground-truthing) of this model revealed additional rare plant populations as well as high to medium quality habitats for rare species. Although the predictive capabilities of GIS-based models are only as good as the variables used to generate them, they can provide useful insight into the dependency of rare species on habitat variables.

The Guadalupe Mountains violet (*Viola guadalupensis* Powell & Wauer) is a rare and unique species of wildflower endemic to the highest elevations of the Guadalupe Mountain range in West Texas. The species was described in 1990 within Guadalupe Mountains National Park (GMNP; Fig 1), Culberson County, TX, and since its discovery has only been recorded from a single location along the East Rim of Frijole Ridge (Fig 2; Powell & Wauer 1990).

At its type locality, this perennial, yellow-flowered violet grows in mats of up to 20 individuals rooted in small openings of a northwest-facing, dolomitized, limestone rock face approximately 2,600 m above sea level (Powell & Wauer 1990). The plants are well shaded by two large Douglas firs (*Pseudotsuga menziesii* Mirb.) and grow in association with rock spiraea (*Petrophytum caespitosum* [Nutt.] Rydb.), Guadalupe valerian (*Valeriana texana* Steyernm.), small rocklettuce (*Pinaropappus parvus* Blake.), Guadalupe leastdaisy (*Chaetopappa hersheyi* Blake.), littleawn needlegrass (*Achnatherum lobatum* Swall.), and a species of sedge (*Carex sp.*; Powell & Wauer 1990).

Little is known about this species' natural history or the specific habitat characteristics needed to maintain its viability. Speculation has been made of its dependency on microclimatic conditions and substrate type; however, these data have only recently been recorded (F. Armstrong, pers comm.). Average temperature from January 2003 to January 2004, at the type locality, was approximately 12.78°C. Relative humidity during the same time interval ranged from <10 to 100% and daytime light intensity during the growing season (May through July 2002) averaged 0.22 log lum/m^2 (F. Armstrong 2004, unpubl. report). To produce rootstalks for chromosome counts, attempts to germinate seedlings in the laboratory discovered that chilling seeds and treating them with gibberellic acid allowed for successful germination (n = 5; C. Blaxland, pers comm.). Seedlings in potting soil became chlorotic, but when lime was added they regained green coloration indicating an affinity for alkaline substrate (C. Blaxland, pers comm.). Although baseline data have been collected, no intensive comparative analysis or significant research has been done at the risk of damaging the population.

Thorough investigations to locate additional populations in seemingly suitable habitat have been conducted along 8 km of the East Rim of Frijole Ridge from the top of Bear Canyon to Lamar Canyon (Powell & Wauer 1990). Despite these efforts, no other populations were found. *Viola guadalupensis* is currently categorized as a National Park Service Species of Concern, yet it appears to be in danger of extinction based on its small population size and lack of significant habitat information. Powell and Wauer (1990:1) had even commented that *V. guadalupensis* "is an immediate candidate for endangered status" for these very reasons.

With this in mind, the Resource Management Office of GMNP has implemented a plan to collect seeds and germinate them in a laboratory setting with the intentions of introducing *V. guadalupensis* to other suitable locations within the park. The objective of this study was to locate suitable *V. guadalupensis* habitat sites within GMNP, using a GIS-based habitat model generated from variables unique to the type locality, and validate those locations with ground surveys.

METHODS

Study Area.—Our study was conducted within the 34,971 ha of GMNP, Culberson County, TX. The Guadalupe Mountain range is a unique biological sky island consisting of Chihuahuan Desert vegetation (*Agave*,

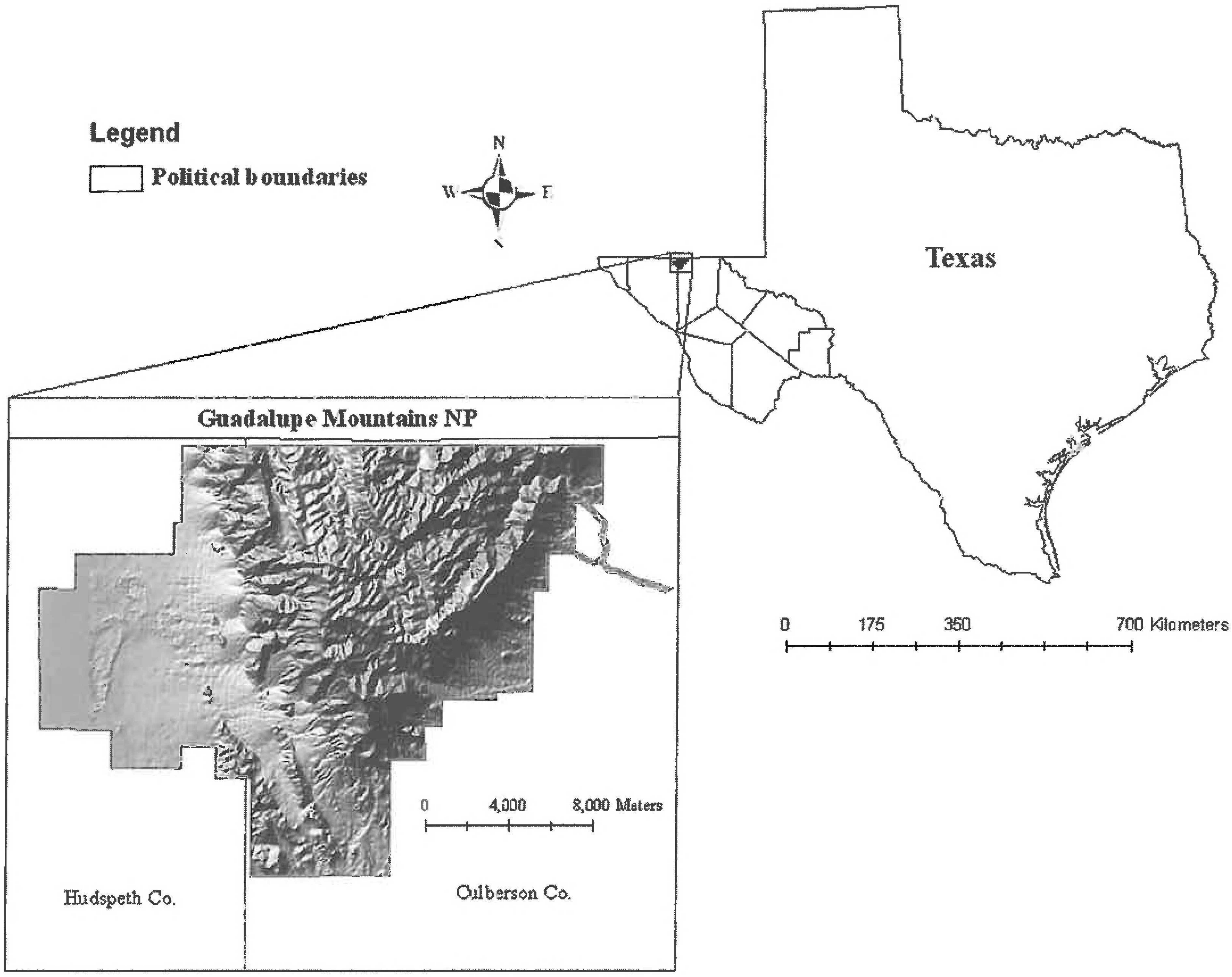

FIG 1. Shaded relief of Guadalupe Mountains National Park located in Culberson and Hudspeth Counties of West Texas.

Yucca, Larrea, Acacia, etc.) at lower elevations (< 2,000 m) and mixed-conifer woodlands of *Pseudotsuga menziesii*, southwestern white pine (*Pinus strobiformis* Engelm.), ponderosa pine (*P. ponderosa* Laws.), pinyon pine (*P. edulis* Engelm.), and various species of oak (*Quercus* sp.) at higher elevations (> 2,000 m). This unique mountain range of the Chihuahuan Desert is the largest limestone uplift in the southwestern United States, formed 250 million years ago by an ancient reef system (Murphy 1984). Mountain summits exceed heights of 2,600 m, shadowing deep canyon systems containing a variety of mountain springs. A 19-year average of temperature and precipitation collected at the 2,455-m elevation automated weather station documented average winter lows of -1.7°C, average summer highs of 23.9°C, and average annual precipitation of 45.0 cm (National Park Service 2005).

Monitoring the type locality.—The condition of the type locality was monitored on 26 May 2006. We compared the counts of individual *V. guadalupensis* plants to a detailed line drawing of individual *V. guadalupensis* plant locations and numbers produced by the Guadalupe Mountains Resource Management Specialist during inventories conducted in 2001, 2002, and 2004. To avoid over estimating the population size, individual plants were conservatively tallied and then averaged between counts for consensus.

GIS model development.—Based on the fact that *V. guadalupensis* had not been observed by park staff or researchers in any of the mesic regions surveyed within the park, we speculated that this species may have specific topographic habitat preferences that include 1) elevations with overall cooler, moister conditions, 2) aspects with minimal hours of direct sunlight, and 3) vertical rock versus horizontal soil substrate as indicated at the type locality. The National Park Service Intermountain Regional GIS Office, in

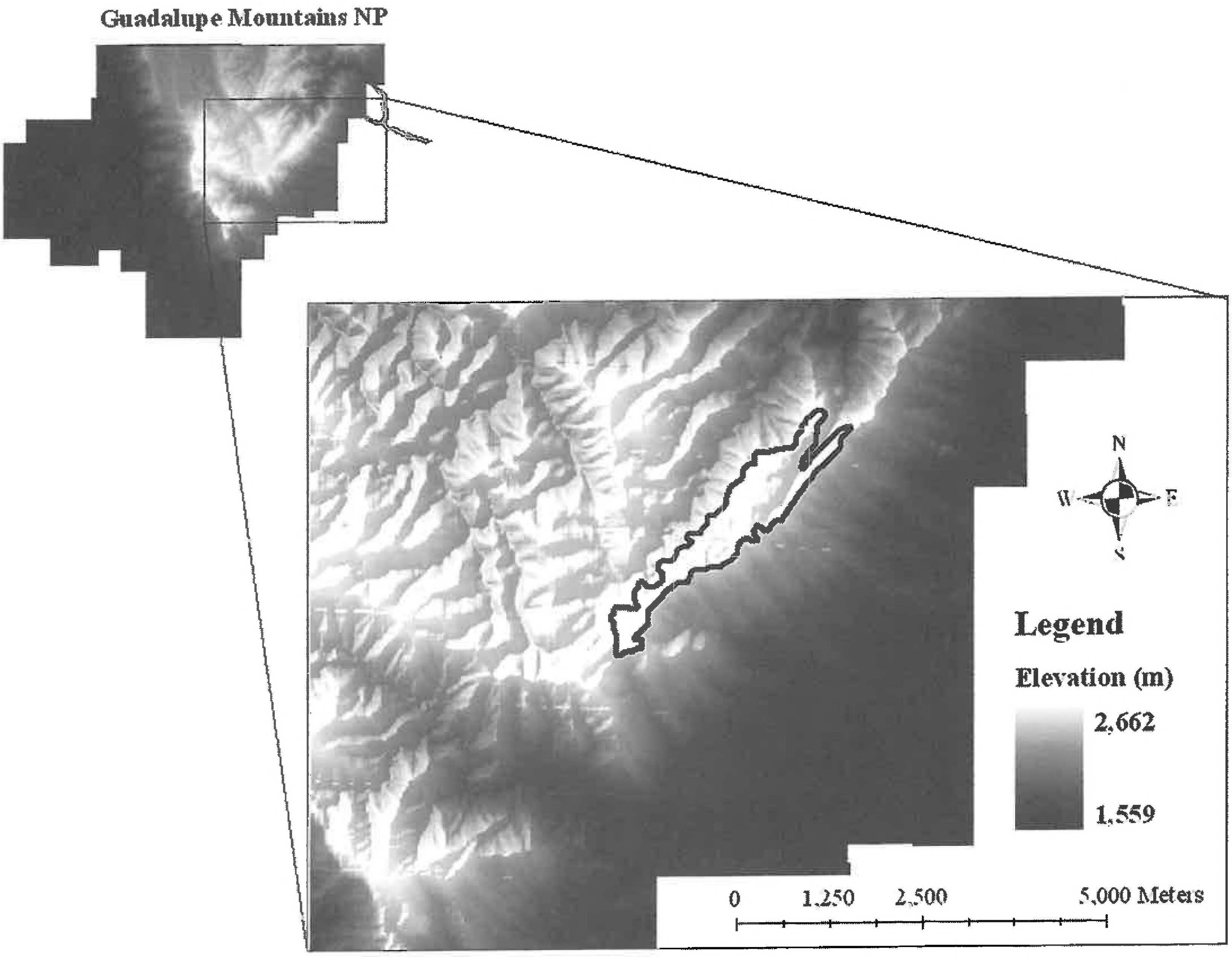

FIG 2. Detailed elevation relief of the East Rim and Frijole Ridge (outlined in black) of Guadalupe Mountains National Park, Culberson Co., TX.

conjunction with GMNP, performed habitat modeling based on these variables to narrow the search areas for potential habitat and suitable locations for establishing additional colonies.

GIS modeling was performed with ESRI's ArcMap Ver. 9.1 software (available from *http://www.esri.com/software/*) incorporating the following parameters in order of priority: 1) elevation bands from 7,800 to 8,000 ft (feet were used for the ease of visually correlating potential sites to USGS topographic maps printed with 40-ft elevation contour intervals), 2) a northwest aspect range from 300 to 330 degrees, and 3) slopes >70 percent. Elevation, aspect, and slope were all derived from a 30-m digital elevation model (DEM) of GMNP obtained from the National Park Service, Natural Resource GIS Data Store.

Using ESRI's ArcToolbox Reclassify tool, DEM cell values were used to separate elevation and aspect into three classes (Class 1 = elevations between 3,500 and 7,800 ft and aspects 0 to 300 degrees, Class 2 = elevations from 7,800 to 8,000 ft and aspects 300 to 330 degrees, and Class 3 = elevations > 8,000 ft and aspects 330 to 360 degrees). The Raster Surface Slope tool was used to divide slope values into two classes (Class 1 = slopes 0 to 70% and Class 2 = slopes >70%). Each class of elevation, aspect, and slope was then assigned a model value of 3, 2, 1, or 0. A model value of three was assigned to the elevation parameters met by Class 3, while model values of 2 and 1 were assigned for the aspect and slope parameters in Class 2, respectively. An assignment of 0 represented all other non-target cell values for every class.

All four model values were unioned together producing a model with seven categories from 0 to 6 displayed as a digital predictive habitat map. Category 0 displayed all non-target parameters; categories 1 and 2 displayed only slope and aspect, respectively. Category 3 displayed criteria for elevation or a combination of slope and aspect. Category 4 displayed areas where a combination of elevation and slope criteria were met, while Category 5 represented areas of both elevation and aspect. Finally, Category 6 displayed locations where all three parameters of elevation, aspect, and slope were met (Table 1).

Model Validation.—Field validation surveys of predicted *V. guadalupensis* sites were conducted May through July 2006. We used Universal Transverse Mercator (UTM) coordinates digitized in ArcMap to find predicted sites where all three criteria were met (i.e. Category 6). A radius of 200 m was investigated around each UTM location to compensate for any inaccuracies of positioning due to poor satellite geometry. The specific characteristics used to determine suitable habitat of predicted locations in the field consisted of north to northwest-facing rock walls with crevices and vegetation similar to that of the type locality, a physically cooler ambient temperature, and shaded areas with sufficient canopy cover to protect the site from direct sunlight. Rock faces <3 × 3 m were ruled out as insufficient space for colonization due to the lack of potential dispersal of plants within the area.

RESULTS

Status of the type locality.—Compared to previous inventories, 20 new individual plants (n = 94) were recorded in 2006. Although no violets were observed to be flowering, several plants possessed seed capsules. No conspicuous differences in vegetative composition were observed when compared to detailed line drawings and photographs from previous inventories.

Model validation -- The model displayed 14 locations meeting all three criteria in Category 6. We investigated a total of nine locations consisting of three sites near Guadalupe Peak (WGP, NGP1, and NGP2), two near Bush Mountain (BMD1 and BMD2), one north of the Bowl (NOB), one near South McKittrick Canyon (SMK), and two locations on Frijole Ridge. Five locations were omitted from investigation due to inaccessibility and by request of the GMNP Resource Management Office, therefore, no site codes were assigned to these locations.

Two of the nine investigated locations predicted by the model on Frijole Ridge revealed populations of *V. guadalupensis*. One of these locations was the type locality (designated VIGU1). The second location revealed a new, isolated population of *V. guadalupensis* in a steep, slot-canyon drainage (approximately 2.1 to 2.4 m wide), on a 35 degree, northeast-facing limestone wall. The site (designated VIGU2) is located off a plateau on the East Rim approximately 2 km northeast of the type locality.

We observed 25 individual *V. guadalupensis* plants at VIGU2 on 26 May 2006, growing largely in a monoculture. Several *V. guadalupensis* plants were located approximately 1.5 m overhead, making an exact count difficult. Although no seed capsules were observed on non-flowering plants, a number of violets still possessed flowers. All violets had noticeably longer petioles and grew predominantly as individual plants rather than in the mat clusters characteristic of violets at the type locality (VIGU1).

Associated plant species of VIGU2 included *Valeriana texana*, bedstraw (*Galium* sp.), and red alumroot (*Heuchera rubescens* L.). Violets were shaded by the steep, canyon walls and a canopy of western hophornbeam (*Ostrya knowltonii* Cov.) and *P. strobiformis*. Other surrounding vegetation consisted of mountain spirea (*Holodiscus dumosus* Nutt.), *Pseudotsuga menziesii*, and *Petrophytum caespitosum*.

Three of the seven sites without violets (WGP, BMD2, and SMK) were considered to be suitable for introduction upon comparison to the type locality. The remaining four locations (NGP1, NGP2, NOB, and BMD1) were considered unsuitable, possessing sparse vegetation and fully exposed rock faces atypical of either violet location.

Twenty-two percent of all survey sites predicted by the model had extant populations of *V. guadalupensis*. Three of the nine sites (33%) were considered to be suitable sites for introduction. Overall, this model had 56% accuracy for predicting suitable or existing *V. guadalupensis* habitat.

Potential locations for introduction.—The first site considered to be suitable was located around WGP and appeared to be very similar to that of VIGU1. This site (designated WGP1) included a steep rock face, shaded by several small *Pseudotsuga menziesii* and *Ostrya knowltonii* trees approximately 40 m down a

TABLE 1. Assignment of target and non-target model parameters to their associated category used to generate the *Viola guadalupensis* habitat model in the Guadalupe Mountains National Park. The desired model parameters of categories 1 through 6 included slopes >70%, aspects between 300 and 330°, and elevations >8,000 ft, respectively. Non-target parameters of Category 0 included all criteria outside the desired parameters. Category 6 was used to identify potential *V. guadalupensis* habitats throughout the park.

Category	Model parameters
0	Non-target parameters
1	Slope
2	Aspect
3	Elevation or slope and aspect
4	Elevation and slope
5	Elevation and aspect
6	Elevation, slope, and aspect

steep drainage. The ambient temperature was physically cooler in the early and late afternoon (1120 h and 1619 h). This rock wall faces north to northwest with a number of crevices and associated vegetation similar to VIGU1. The location is approximately 15 to 20 m long and 5 to 8 m tall with an elevation of approximately 2,500 m.

The second potential site (BMD2) possessed very tall and wide north- and west-facing cliff walls that appeared to be suitable habitat, however, as investigation of the area progressed into the afternoon (1300 h), the rock walls were observed to be more exposed to direct sunlight than earlier that morning (1100 h) as a result of sparse canopy cover. However, one rock wall, in particular, was considered suitable because it met all desirable criteria outlined by the model and remained shaded by *Pseudotsuga menziesii* and *Quercus* sp. at the time of investigation.

Finally, the third potential site near South McKittrick Canyon (SMK) possessed a number of small rock walls (between 3 × 3 m and 5 × 5 m) with one single location (designated SMK2) significantly shaded by *Ostrya knowltonii*, *Pinus ponderosa*, *Pinus strobiformis*, and *Pseudotsuga menziesii*. Data loggers, programmed to record light intensity, relative humidity, and temperature, were placed at VIGU1, VIGU2, WGP1, BMD2, and SMK2 for future comparison of microclimate data.

DISCUSSION

Significance of GIS-based predictive modeling.—The results of this study indicate two essential aspects for understanding the significance of this predictive model when compared to previous ground surveys and the habitat requirements of *V. guadalupensis*. First, the GIS-based habitat model located the type locality and an additional population of *V. guadalupensis* along Frijole Ridge, as well as three potentially suitable habitats for introduction west of this region. Since its discovery in 1990, extensive ground surveys of seemingly suitable habitat have been unable to locate additional populations (Powell & Wauer 1990). Based on our results, this study supports the relative usefulness of GIS-based habitat models for predicting the distribution of rare species consequently decreasing the ineffectiveness of random surveys.

Second, *V. guadalupensis* displays an affinity towards steep slopes, northerly aspects, and high elevations on Frijole Ridge. These results substantiate our assumptions that *V. guadalupensis* have specific topographic habitat preferences toward the variables used to develop our model. It is important to consider the fact that violets at VIGU2 were positioned on a northeast aspect rather than a northwestern aspect characteristic of VIGU1. This observation might indicate that aspects ranging from 300 to 45 degrees (northwest to northeast) may be a better representation of this species' aspect preference than those strictly between 300 and 330 degrees.

Model efficacy.—Considering two out of the nine predicted locations represented violet populations, while the remaining seven did not, suggests that 1) the variables used to develop the model were not specific enough to locate habitats strictly containing *V. guadalupensis* or 2) *V. guadalupensis* is restricted only to these two locations on Frijole ridge and may have not had the opportunity to disperse to other areas. It is also important to take into account that three of the five locations not ground-truthed in this study were also located along Frijole Ridge. It is possible these locations may possess populations of *V. guadalupensis*. Further investigation into these areas is suggested in order to allow for a more complete model evaluation and to confirm the distribution of *V. guadalupensis* using this GIS-based habitat model.

Because the efficacy of a predictive model is dependant on the variables used to generate it, accurate information of habitat requirements for a species is necessary for the development of an accurate predictive model. Cherrill et al. (1995) stated that the rarity of a species greatly affects a model's efficacy to predict species-habitat distributions. Their model was generated from variables of known locations to predict rare and common species compared to traditional field surveys. Their results found a higher rate of accuracy for predicting common species than those of rare species. These results were dependent on the amount of information available for each species (Cherrill et al. 1995). Additional species-habitat information of *V. guadalupensis* (e.g., microhabitat conditions) will likely enable resource managers to generate a more effective model for predicting *V. guadalupensis* distribution and abundance.

Conservation and management.—Proper management of the two *V. guadalupensis* sites is vital for its continued existence within the Guadalupe Mountains. The distance between VIGU1 and VIGU2 (2 km) suggests that gene flow between these populations is unlikely. Because the most promising mechanism of seed dispersal across such distances is wind (Davies et al. 2004), this mechanism is improbable due to the density of vegetation around VIGU1 and the steep, narrow, rock walls surrounding VIGU2. These conditions likely protect these areas from wind rather than contribute to the use of wind-based seed dispersal. Consequently, understanding seed dispersal and genetic diversity between these two populations is essential for its conservation. Additionally, we suggest that introduction of violets into additional areas should include representatives from both locations to improve genetic diversity within new areas to prevent an additional bottleneck effect.

Although the locations of this species are far from human impact, several environmental factors may threaten the persistence of these populations. The accumulation of ladder fuels within the park has created conditions suitable for catastrophic wildfires along the East Rim. This could result in the burning of *V. guadalupensis* habitat or a reduction in the number of shade trees surrounding the area causing fatal heat temperatures from exposure (F. Armstrong, unpubl. report). Predation of leafs and seedpods by small mammals has been hypothesized to occur at VIGU1 (F. Armstrong 2002 and 2004, unpubl. field notes). Even though there has been no direct observation of this activity, seed predation will likely affect the reproductive success of individual plants, reducing overall genetic diversity and dispersal.

Continued monitoring of both *V. guadalupensis* sites and comparing the long-term microhabitat conditions of known violet sites to potential introduction sites will provide a better understanding of specific habitat requirements for introduction and habitat management. The two populations of violets, as well as the three uninvestigated sites on Frijole Ridge, should also be considered during fire management planning to prevent unfavorable conditions due to catastrophic wildfires along the East Rim.

The habitat model developed by the National Park Service to predict potential *V. guadalupensis* habitat has provided critical baseline data for additional investigations and research within GMNP. Due to the success of finding an additional population and other suitable sites for introduction, resource managers can utilize this information for continuing plans to proliferate and conserve *V. guadalupensis* populations with potential success.

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REFERENCES

Cherrill, A.J., C. McClean, P. Watson, K. Tucker, S.P. Rushton, and R. Sanderson. 1995. Predicting the distributions of plant species at the regional scale: a hierarchical matrix model. Landscape Ecol. 10:197--207.

Davies, S., A. White, and A. Lowe. 2004. An investigation into the effect of long-distance seed dispersal on organelle population genetic structure and colonization rate: a model analysis. Heredity 93:566--576.

Husveth, J.J. 2003. Ecological surveys of rare plants and plant communities in eastern Anoka County, Minnesota. Conservation Biology Research Grants Program, Division of Ecological Services, Minnesota Department of Natural Resources. http://files.dnr.state.mn.us/ecological_services/nongame/projects/consgrant_reports/2003_Husveth_sign2 (Accessed October 2006).

Imm, D.W., H.E. Shealy Jr., K.W. Mcleod, and B. Collins. 2001. Rare plants of southwestern hardwood forests and the role of predictive modeling. Nat. Areas J. 221:39--49.

National Park Service. 2005. Fire Management Plan, Guadalupe Mountains NP, Texas.

Powell, A.M. and B. Wauer. 1990. A new species of *Viola* (Violaceae) from the Guadalupe Mountains, Trans-Pecos Texas. Sida 14:1--6.

van Manen, F.T., J.A. Young, C.A. Thatcher, W.B. Cass, and C. Ulrey. 2005. Habitat models to assist plant protection efforts in Shenandoah National Park, Virginia, USA. Nat. Areas J. 25:339--350.

Vogiatzakis, I.N. 2003. GIS-based modelling and ecology: a review of tools and methods. Geographical Paper no. 170. Department of Geography, The University of Reading, Whiteknights, U.K. http://www.geog.rdg.ac.uk/Research/Papers/GP170 (Accessed: October 2006).

Wu, X.B. and F.E. Smeins. 2000. Multiple-scale habitat modeling approach for rare plant conservation. Landscape Urban Planning 51:11--28.